Concrete mix design for X-and gamma shielding

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Abstract

The design of X-ray or gamma ray radiographic exposure room requires some calculations on shielding to provide safe operation of the facility and minimum exposure to radiation workers. Careful design can lead to economical installations with minimal barriers. The design depends on such factors as: maximum energy, maximum intensity, permitted full-body dosage, workload, use factor, occupancy factor, maximum dose output and shielding materials.

Choice of material for a barrier depends on convenience and cost. The radiographic exposure room is usually made of normal concrete with density of about 2.3 – 2.4 g/cc. Normal concrete is often used for construction of exposure room because of cheap and ease of construction.

This paper explained and discussed the optimum mix design for normal concrete used for X-and gamma shielding.

Introduction

All works with radiation sources involved a risk of exposure to radiation, which is known as occupational exposure. However, as a general rule, all workers must take efforts to ensure that the exposure he received is kept to a minimum possible. This is known as 'As Low As Reasonably Achievable' (ALARA) concept. For industrial radiography, only external radiation exposure is to be considered. If a radioactive material gets inside the human body it gives rise to an internal radiation exposure, which required quite different method of control. The external radiation exposure is controlled by applying the three radiation safety principles namely: Working time, Distance and Shielding

Radiation exposure received by a radiation worker in radiation area is directly proportional to length of time that the individual spends in that area. Limiting the time spent in a radiation area is one of the main methods to reduce the amount of radiation exposure received by a radiographer. In reality, this can be achieved by proper planning of the job to be carried out and at the same time distributing the work evenly among radiographers involved.

Maximizing distance from a radiation source is a very effective means of protecting radiographer. This is because radiation exposure decreases drastically with increasing working distance from the source. The third method of controlling external radiation exposure is by placing a shielding between the source and the radiographer. Shielding could be made of any suitable materials and is placed as a barrier between the radiation source and workers. In practice, lead and concrete are used as

common shielding materials for x- and gamma rays, while water, wax, boron and concrete are used for neutrons.

Shielding effectiveness for each material depends on its atomic number, density and thickness. It is also dependent on the energy of radiations. Higher energies of radiations are less likely to interact with electrons. Thus, they are more penetrating.

Concrete as a shielding material

The depth of penetration for a given photon energy is dependent upon the material density (atomic structure). The more subatomic particles in a material (higher Z number), the greater the likelihood that interactions will occur and the radiation will lose its energy. Therefore, the denser a material is the smaller the depth of radiation penetration will be. Materials such as depleted uranium, tungsten and lead have high Z numbers, and are therefore very effective in shielding radiation. Concrete is not as effective in shielding radiation but it is a very common building material and so it is commonly used in the construction of radiation vaults.

Most designers and builders today are familiar with the advantages of using very high density concretes for radiation shielding. Not so well known is the excellent economy which can result from the use of normal site cast concretes with locally available aggregates when space and other factors do not absolutely demand that the desired protection be achieved within minimum dimensional limits. The effectiveness of any biological shielding material is related only to its mass and concrete has an obvious advantage in this highly specialized field of construction because of its exceptionally low cost per pound. Lead is an ideal shielding material where thinness alone is a dominant consideration but it is far more expensive and has poorer structural properties than does concrete.

Structure of concrete

Concrete is a composite material composed of coarse granular material (the aggregate or filler) embedded in a hard matrix of material (the cement or binder) that fills the space between the aggregate particles and glued them together. Aggregates can be obtained from many kinds of materials, although we mostly use of the material of nature- common rock. Aggregates should be inert and act as filler materials. For simplification, aggregate can be classified as fine and coarse aggregates.

Cement can be formulated from many diverse chemicals. “Cement” is a generic term that can be apply to all binders. In civil engineering, the binders are Portland cement, calcium aluminate cement or epoxy resin. In concrete construction, most concrete used Portland cement as a binding material. Photograph 1 shows that the cross section of concrete sample which uses granite as coarse aggregate.

Photo 1: Cross-section of concrete sample (2.5X)

Setting of Concrete

The chemical composition of Portland cement consists of 50% tricalcium silicate (C3S), 25% dicalcium silicate (C2S), 12% tricalcium aluminate (C3A), 8% tetracalcium aluminoferrite (C4AF) and 3.5% calcium sulfate dihydrate (CSH2) or called as gypsum (Mindness 1981). Setting of Portland cement starts from hydration process between water and the surface of particles C3A to form hydrated calcium silicate to give initial strength of the cement. C3S becomes a gel in a few hours after setting and after 14 days the quantity of gel formation during this setting will influence the initial strength of concrete. Hydration of C2S (and also hydrationC3S) which occur slowly will contribute to 14 and 28 day strength and the strength after 28 days.

Concrete Mix Design

Concrete mix design can be defined as a process of selection of material quantity in concrete. The purpose is to produce a concrete not only cheap but also meet the intended strength and durability.

In mix design process, the following factors have to be considered;

a) minimum compressive strength required,
b) water to cement ratio
c) type of cement
d) durability
e) workability and water content
f) choice of aggregate
g) cement content
h) aggregate content

Compressive strength

Compressive strength determined from concrete cube test is the important measurement to evaluate the intended quality of concrete. This compressive strength is tested when the concrete cube reach the age of 7 days and 28 days. The minimum cube compressive strength specified by structural designer at 28 days determined the grade of concrete. Table 1 shows the grade of concrete in construction.

Table 1:Concrete Grade in Construction

Grade No.	**Application**
7~10	Concrete without reinforcement
15	Lightweight concrete
20~25	Normal concrete
30	Post stressed concrete
40~60	Pre-stressed concrete
70~100	High performance concrete

Weight proportion method

The mix design method can be classified into three methods; Fix method (CP110:1972), weight proportion method (JKR) and mix design method (Department of environmental UK, DoE method and American Concrete Institute, ACI method).

JKR method is used in designing mix for normal concrete of radiation shielding (Table 2). For example, 1:2:4 means 1 proportion of cement, 2 proportion of sand and 4 proportion of coarse aggregate by weight.

Table 2: JKR method

Name of mix	Min. Compressive Strength (N/mm^2)		Max aggr. Size	Min. Cement (kg/m^3)
	7 days	28 days		
1:1:2	20	30	20	380
1:1.5:3	17	25.5	20	361
1:2:4	14	21	20	321
1:3:6	8	12.5	25 or 38	-

In this experiment, mixes as in Table 3 were used to obtain the maximum density of concrete. In all mixed water /cement ratio of 0.5 -0.7 is used and adjusted to satisfy the medium slump.

Table 3: Design mix for obtaining high density

Mix	**Mix identity**	**Cement (kg)**	**River sand (kg)**	**Crushed granite (kg)**
1:1:2	101020	10	10	20
1:1.5:3	101530	10	15	30
1:2:3.3	102033	10	20	33
1:2:4	102040	10	20	40
1:2.5:2.9	102529	10	26	29
1:3:4	103040	10	30	40
1:3:6	103060	10	30	60

Results and discussion

Fig. 1 shows data of mix proportion versus density of concrete. As the amount of coarse aggregate is increased, the density will increase. However there is a limit as too much coarse aggregate make more difficult to compact the concrete and result in lower density. Too rich the cement content also will reduce the density. Therefore it is found that mix 1;2:4 is producing highest density for normal concrete.

Similar pattern can be observed for mix proportion versus strength. However the high amount of cement increases the strength more pronounce than the density.

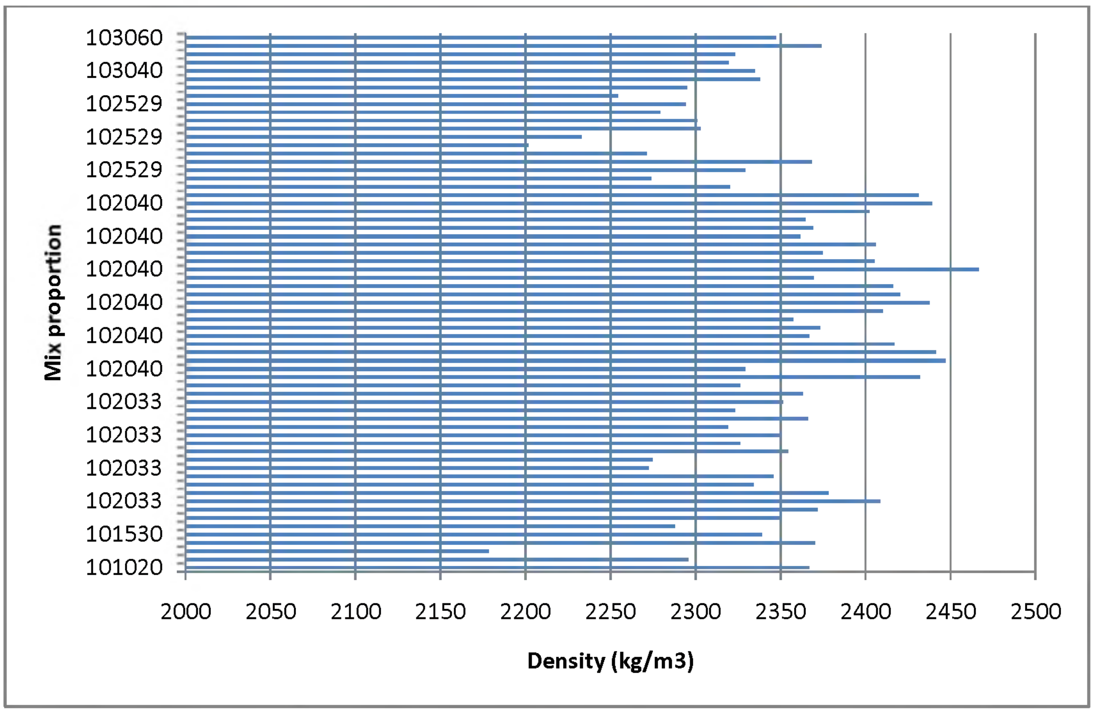

Fig. 1: Mix proportion vs density

Conclusion

The optimum mix proportion to produce concrete density of 2300 – 2400 kg/m3 is 1:2:4. The water to cement ratio is maintained between 0.5 and 0.55 to produce moderate slump and workability.

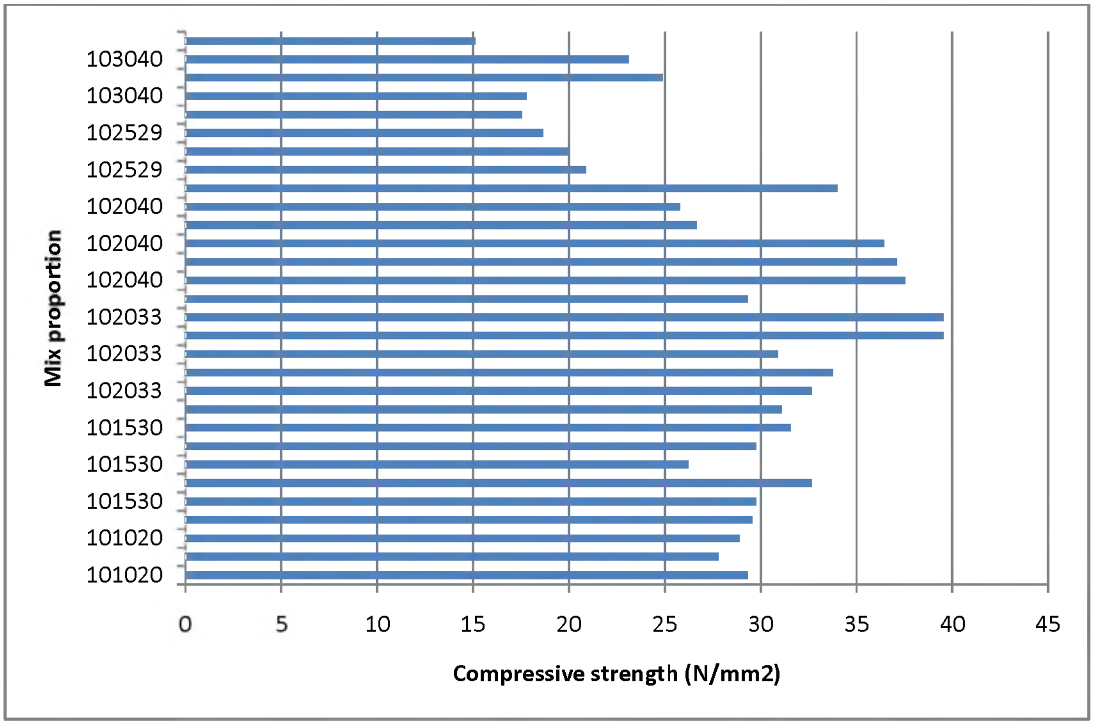

Fig. 2: Mix proportion vs. strength

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